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Space LLC

Affording a Return to the Moon by Leveraging Commercial Partnerships

Are human missions to Deep Space economically affordable & technical feasible if we change our strategy?

Charles Miller
President, NexGen Space LLC
spacepolicy@me.com
September 30, 2015

FISO Telecon Presentation

NASA-funded Study by NexGen Space
Background & Purpose

If America can put a Man on the Moon, …
Why can't we put a Man on the Moon?

- NASA has made 3 major attempts in the last 45 years to recreate the magic of Apollo
  - Each of the attempts has failed because of affordability
  - Every previous attempt was estimated to cost hundreds of billions
- NASA's Office of the Chief Technologist (Emerging Space Office) funded this economic research analysis
- RESEARCH QUESTIONS:
  - What if we leverage commercial partnerships (like COTS) for human missions to deep space?
  - Is it technically feasible?
  - What would it cost?

NexGen Study Team

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Charles Miller (Principal Investigator, Business & Economic)

- Nearly 30 years experience in space industry
- Former NASA Senior Advisor for Commercial Space
- Co-founder Nanoracks LLC, and former President and CEO of Constellation Services International, Inc.

Dr. Alan Wilhite (Co-Principal Investigator, Technical)

- 40 years of systems engineering at NASA and Georgia Tech
- More than 60 published articles and several book chapters on space systems engineering.
- Former Director of the NASA's Independent Program Assessment Office

Edgar Zapata, NASA KSC (Life Cycle Cost Analysis)

- Has worked with NASA at KSC since 1988 with responsibility for Space Shuttle cryogenic propellant loading systems, and related flight and ground propulsion systems.
- For last 20 years has translated real-life human spaceflight operational experience and lessons learned into improvements in flight and ground systems design, technology, processes and practices. He has participated in most major agency-level human exploration studies.

David Cheuvront (Risk, Safety & Mission Assurance)

- David Cheuvront has 37 years of aerospace experience, including 19 years at NASA JSC. At Rockwell International, Cheuvront solved key maintenance challenges in the preliminary design of the Space Station *Freedom*, and was hired by NASA JSC to solve problems in reliability and maintainability in human spaceflight.

Robert Kelso (Lunar Robotics & ISRU)

- 37 years at NASA-Johnson Space Center, including serving as a Shuttle Flight Director in JSC's Mission Control Center. Kelso led NASA's efforts to leverage commercial lunar robotics developments for several years.

American University (AU) School of Public Affairs & Dr. Howard McCurdy

- Dr. McCurdy is an AU Professor of Public Policy and has authored seven books on the American space program, including *Faster-Better-Cheaper: Low-Cost Innovation in the U.S. Space Program*, *Inside NASA: High Technology and Organizational Change*, and *Space and the American Imagination*.

Independent Review Team

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- Independent Review conducted on March 11, 2015
  - Full day briefing, followed by detailed feedback in 21-page report.

- Joe Rothenberg (Chairman)
- Jim Ball
- Hoyt Davidson (Econ. lead)
- Frank DiBello
- Jeff Greason
- Gene Grush (Technical lead)
- Alexandra Hall (Benefits lead)
- Jeffrey Hoffman (S&MA lead)
- Ed Horowitz
- Steve Isakowitz
- Christopher Kraft
- David Leestma (Cost Est. lead)
- Michael Lopez-Alegria
- Thomas Moser
- James Muncy
- Gary Payton
- Eric Sterner
- Will Trafton
- James Vedda
- Robert Walker
- Gordon Woodcock

NASA's Apollo Program

Set American Expectations about how to do Human Exploration

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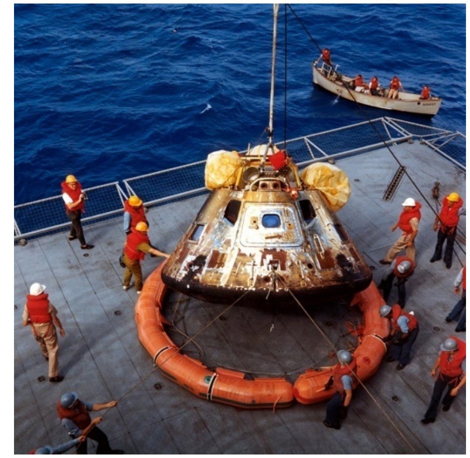
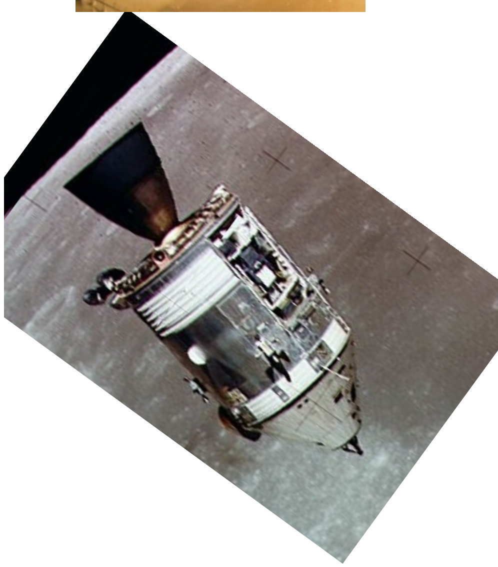
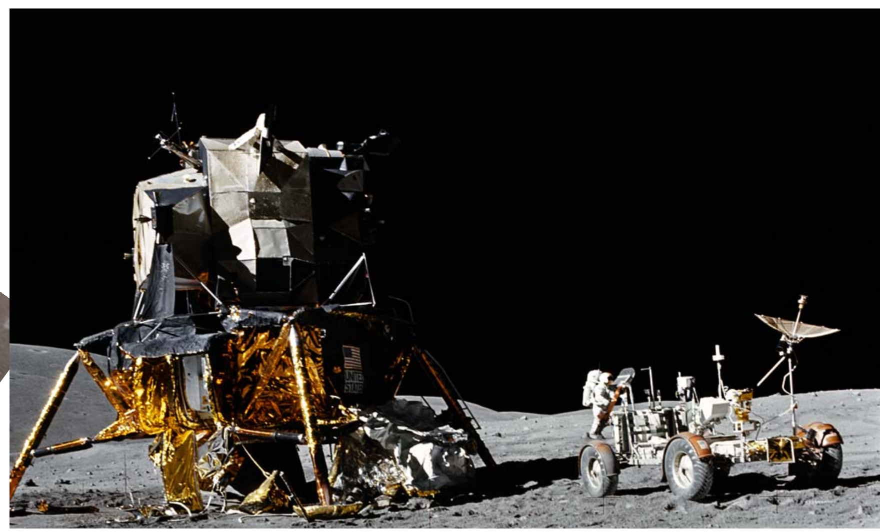
Kennedy Moon Speech

May 1961

"before this decade is out, land a man on the Moon and return him safely to Earth."







Apollo Lunar and Mars Funding Plans

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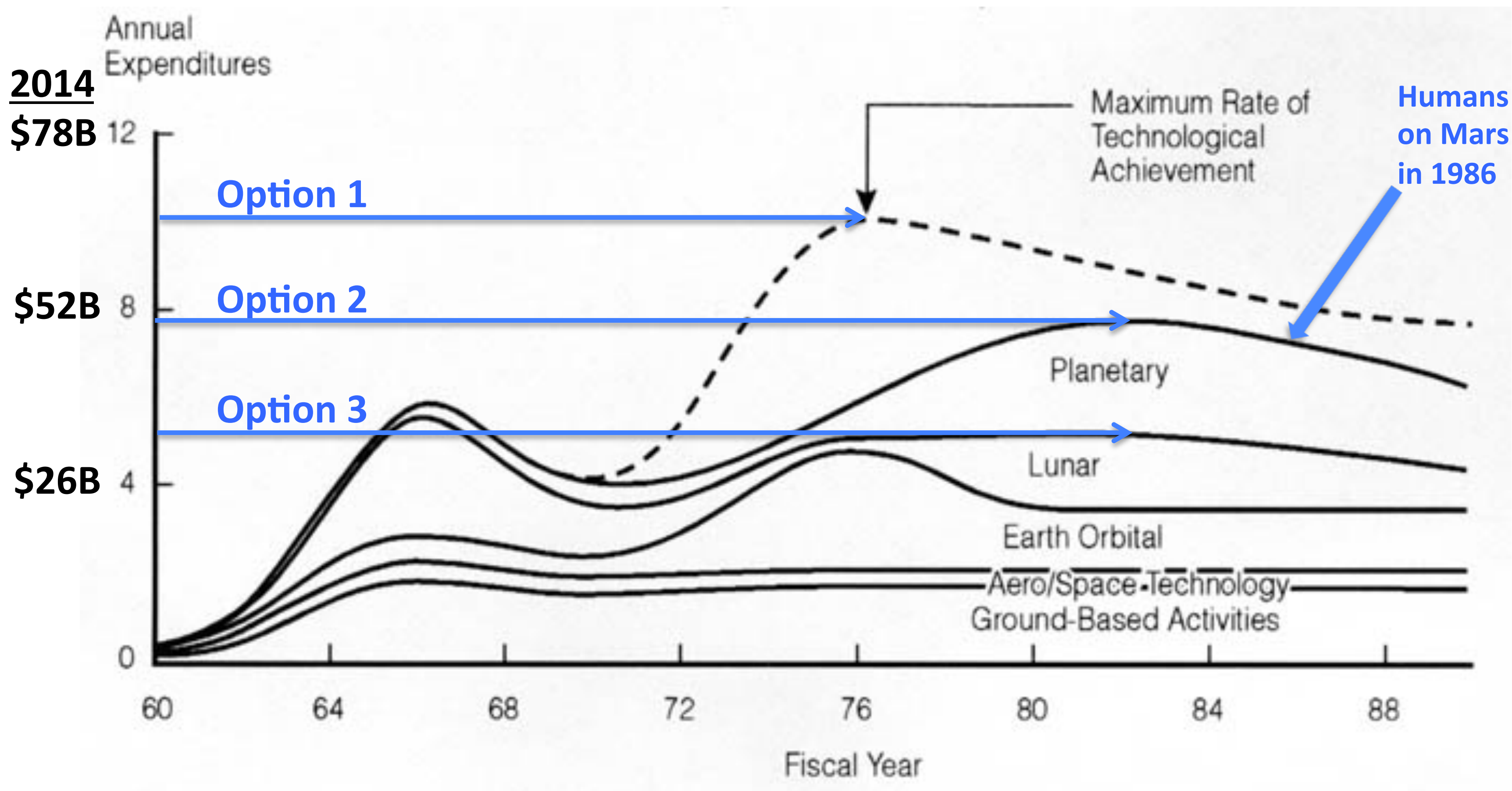
Three levels of space activity studied by Space Task Group in 1969. (NASA)



NASA SP-4221

Reaction from Nixon White House

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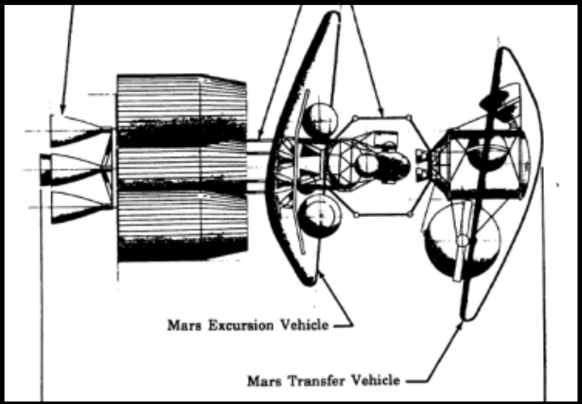
- Cancellation of final three flights to the Moon
- Cut NASA's budget to a low of $14.5 billion (FY2014)
  – Less than half of STG's recommended minimum
- On March 7, 1970, released following statement:
  – ***Space expenditures must take their proper place within a rigorous system of national priorities … What we do in space from here on in must become a normal and regular part of our national life and must therefore be planned in conjunction with all of the other undertakings which are important to us.***
- Approval to build reusable launch vehicle (RLV) that would fly 50 times per year at $10 million per launch

Announcing Space Exploration Initiative (SEI)
July 20, 1989 on steps of the National Air & Space Museum

- Begin operation of the International Space Station in the 1990s
- A permanent Base on the Moon (2009)
- A Human Mission to Mars (2019)
- Tasked Vice President and White House National Space Council to develop options

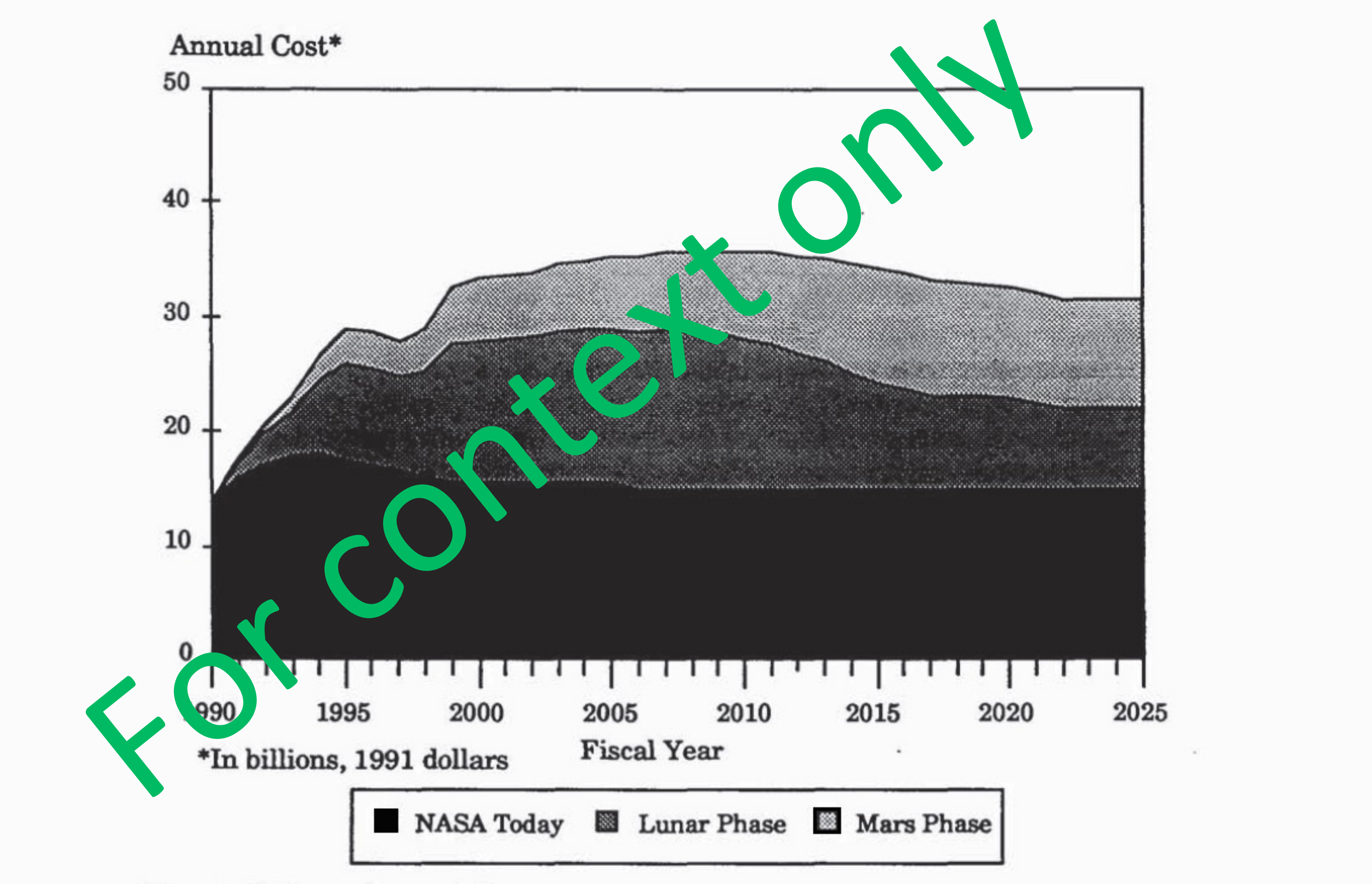


We must commit ourselves anew to a sustained program of manned exploration of the Solar System, and yes the permanent settlement of space. We must commit ourselves to a future where Americans and citizens of all nations will live and work in space.

To seize this opportunity I am not proposing a 10-year plan like Apollo, I am proposing a long-range continuing commitment.

President George H. W. Bush – July 20, 1989

1991 Space Exploration Initiative



1991 Space Exploration Initiative

Required $25B/year increase to NASA budget for lunar (only)

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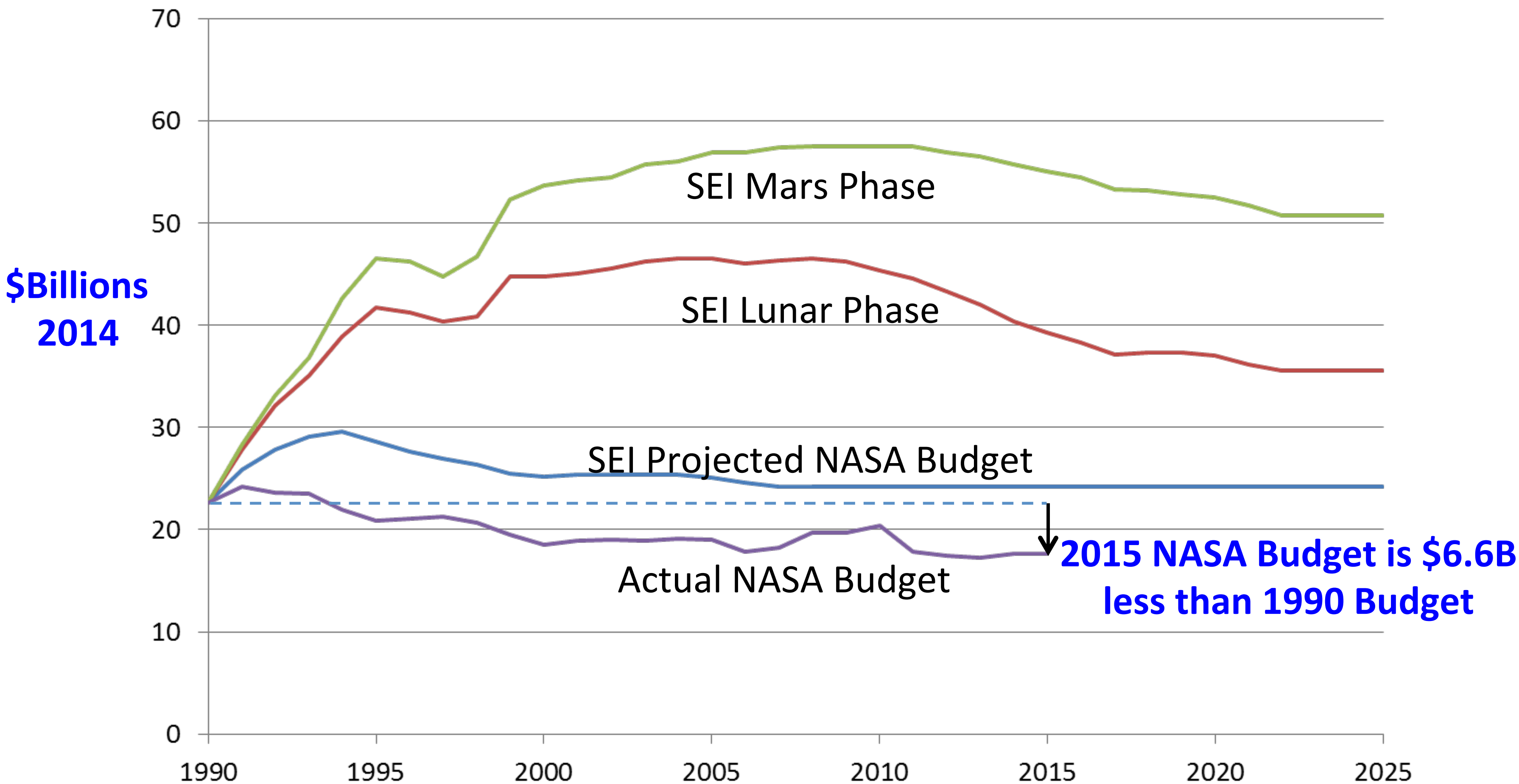

Response to SEI

- NASA 90-day study estimated SEI's long-term cost
  - **Approximately $983 (2014) billion dollars**
- White House and Congressional reaction to NASA plan was hostile
  - primarily due to the cost estimate
- Clinton Administration officially removed human exploration from the national agenda in 1996.

Reactions from Bush 41 White House

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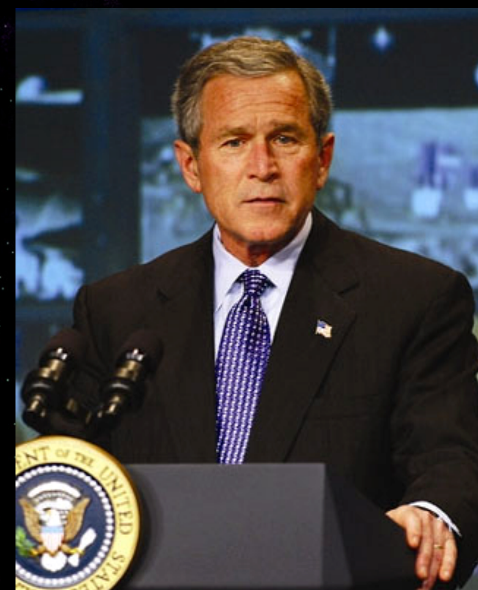
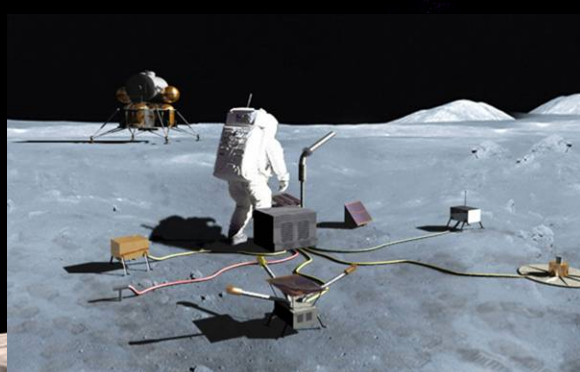
- Mark Albrecht, Executive Secretary, National Space Council
  - *"We were just stunned, felt completely betrayed.* ***Vice President Quayle was furious.*** *The 90-day Study was the biggest 'F' flunk, you could ever get in government.*
  - *The real problem with the NASA plan was not that we didn't think the technology was right, but that it was just the most expensive possible approach.* ***It was just so fabulously unaffordable, it showed no imagination."***
    - Thor Hogan, "Mars Wars: The Rise and Fall of the Space Exploration Initiative"
- Former President George H. W. Bush
  - ***"I got set up"***
    - Warren Leary, *New York Times*, 17 December 2003

A Bold Vision for Space Exploration Jan. 2004
leading to the "Constellation Program"

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop and fly the Crew Exploration Vehicle no later than 2014 (goal of 2012)
- Return to the Moon no later than 2020
- Extend human presence across the solar system and beyond





"It is time for America to take the next steps.

Today I announce a new plan to explore space and extend a human presence across our solar system. We will begin the effort quickly, using existing programs and personnel. We'll make steady progress – one mission, one voyage, one landing at a time"

President George W. Bush – January 14, 2004

NASA's Deep Space Human Exploration program
Encounters Budget Reality (Again)

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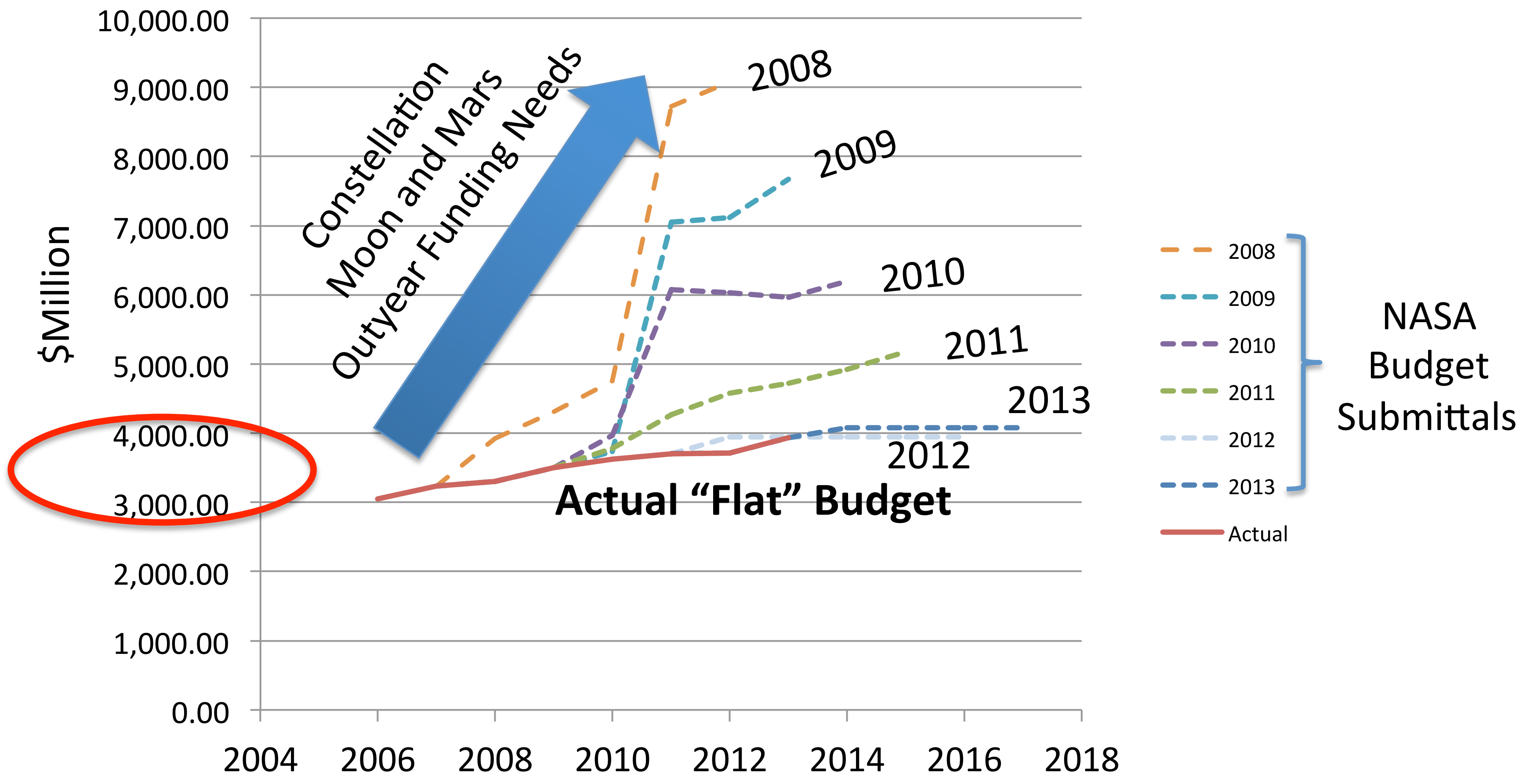

What If?

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- What if we could develop a permanent human settlement on the Moon
- For about $3 Billion per year (FY2014)
- By leveraging commercial partnerships?

What If?

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- We could develop a lunar “export”
  - that would pay enough to cover the costs of operating that permanent lunar base?

What If?

- We applied lessons learned from NASA's highly-successful public-private-partnerships?
  - ISS Commercial Orbital Transportation Services (COTS)
  - ISS Commercial Resupply Services (CRS)
  - ISS Commercial Crew

Lessons Learned from Partnership Approach to NASA ISS Cargo Requirements

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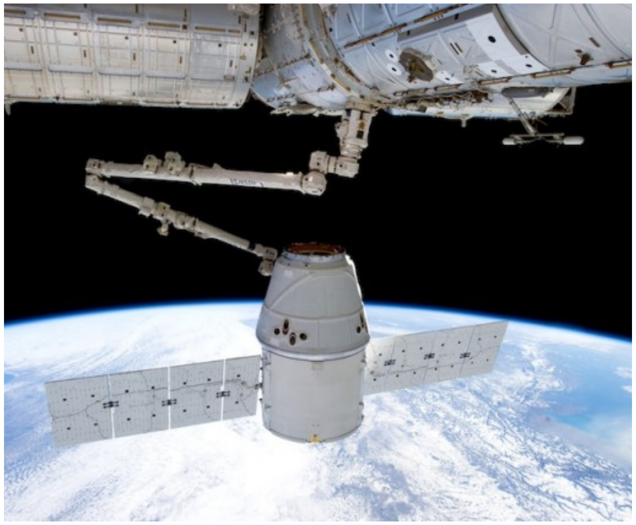
- Started in 2006
  - Dec. 2010 - SpaceX first private company to successfully launch & return a spacecraft from orbit
  - May 2012 - SpaceX first private company to launch a capsule that docks with the ISS & safely return
  - Jan. 2014 – OSC Cygnus arrives at the ISS

- **Total NASA Up-front investment = ~$740M.**

- Private Investment
  - SpaceX invested **~$200M** = Musk ~$100M + Founders Fund, Draper Fisher Jurvetson ~$100M
  - OSC invested **~$150M**



- NASA Investment yielded 2 new launchers & 2 new spacecraft
  - NASA audits confirm up-front development costs for the Falcon 9 were ~ $300M total

Traditional vs NewSpace
Cost Comparisons

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- In 2011, NASA estimated cost of …
  - Developing Falcon 1, Falcon-9, and Dragon
  - Using NASA-Air Force Cost Model (NAFCOM)
- PURPOSE:
  - Compare traditional development vs commercial partnerships
- RESULTS:
  - NASA estimated cost, using traditional methods, at $3.977B
  - Actual cost was $400-500M
- CONCLUSION:
  - **Traditional development estimated 8-10 times the actual cost for SpaceX to develop these same systems**
    - Falcon 9 Launch Vehicle NAFCOM Cost Estimates, August 2011, NASA Associate Deputy Administrator for Policy: http://www.nasa.gov/pdf/586023main_8-3-11_NAFCOM.pdf

SPACEHAB History

- SpaceHab was a commercial microgravity venture
  - Allowed use of Shuttle through NASA Space Act Agreement
- SpaceHab raised $200 million in private financing to commercially develop mid-deck Shuttle modules
  - **~$150 million for DDT&E and manufacturing two flight modules**
- Congress mandated independent cost assessment by NASA using traditional government procurement practices
  - Price Waterhouse used NASA MSFC's standard cost model tool to estimate that it would cost $1.2 Billion
  - **8 times what it cost SpaceHab to develop system using commercial practices and methods!**

- Final Report, An Independent Analysis, Industry Lessons Learned Barriers to establishing commercial partnerships and Achieving Best Practices, NexGen Space LLC, January 18, 2013

What Is the Evolvable Lunar Architecture?

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- Three Phases to the Evolvable Lunar Architecture
  - Phase 1: Human Sorties to Equator / Robotic Prospecting Poles
    - Key transition point to Phase 2 – When LEO on-orbit propellant storage and transfer is available (LOX-H2 or LOX-Kero)
  - Phase 2: Sorties to Poles & ISRU Capability Development
    - Key transition point to Phase 3 – When Lunar ISRU, storage and transfer (LOX-H2) & a reusable lunar lander (LOX-H2) is available
  - Phase 3: Permanent Lunar Base transporting propellant to L2
    - Assume transport for 200+ MT of propellant to L2 every year for Mars EDS
- Earth orbit rendezvous, and later propellant transfer
- Incrementally develop and insert reusable elements
  - SpaceX Dragon V2.1, Boeing CST-200, Sierra Nevada Dream Chaser
  - Partially-reusable and reusable LVs as they are developed
    - E.g., SpaceX's Falcon 9R, United Launch Alliance "Vulcan", and Blue Origin LV
- Assessed 2 specific tech approaches (SpaceX & ULA)

How Does it Leverage Commercial Partnerships?

- A partnership with NASA using proven commercial methods, practices and suppliers
  - NASA as a customer of "propellant" to lunar orbit for going to Mars
  - Privately-owned and –operated. NASA never acquires ownership of lunar infrastructure
  - Use methods proven by COTS, CRS and Commercial Crew
  - Leverage and use existing technologies to maximum extent possible
  - Two independent partner-solutions to provide redundancy, align incentives and drive innovation across the lunar architecture
  - Transition to "International Lunar Authority" to reduce risk to both USG and private industry, to efficiently manage lunar operations, and to seamlessly integrate our international partners

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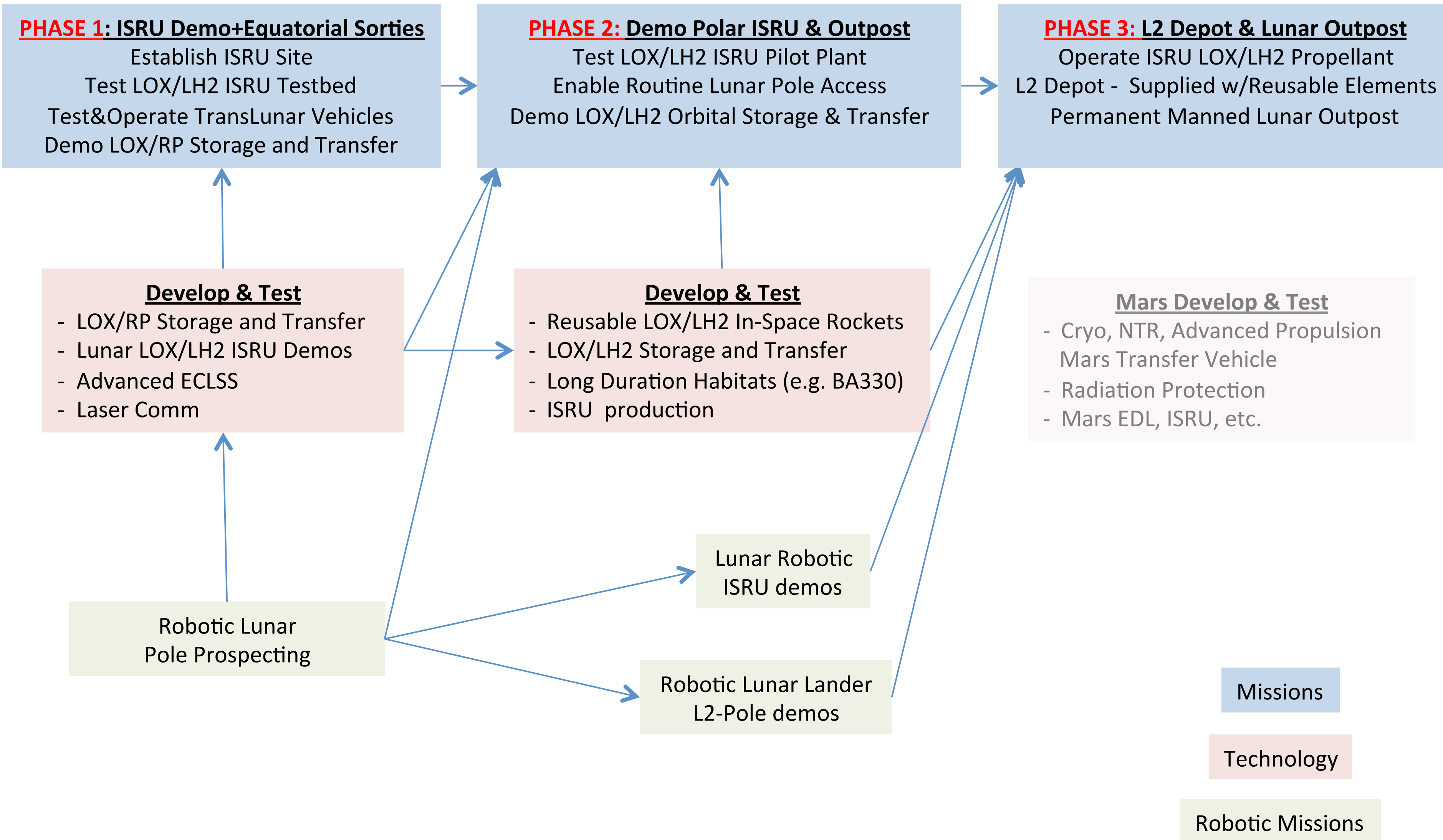
Evolvable Lunar Architecture
Three Phased Evolution to L2



Integrated Risk Summary

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- Risk strategies incorporated at inception for greatest benefit
  - Resilient Architecture concepts provide flexibility, adaptability and sustainability
- Business, safety, and technical risks considered together
  - Multiple prospecting rovers confirm resource availability and conditions
  - Test flights to accomplish low criticality objectives before use in critical role (e.g., landing of cargo before crew)
  - Multiple launches with contingency flights and multiple providers
    - High operational reliability, rapid reliability growth, recurring cost advantages, and efficient utilization of personnel and infrastructure
  - Contingency assets serve multiple roles (e.g., spare later becomes primary)
  - Incremental build-up of capabilities (e.g., ISRU) with repetition of like missions
  - Leverage benefits of reduced launch costs and frequent flights
    - Optimization for robustness, reliability, and lower costs
  - Commonality and interoperability reduces cost and spares availability risk

Reducing Risk of Investing in Comm'l Lunar Base
Lunar Governance Options Analysis

- Significant risks inhibit private investments in lunar base
  - E.g., US Government is not a good partner, or customer
- Evaluated "governance" options to reduce system risks
  - Looking for win-win for both partners

Governance Models / Figures of Merit	Baseline (ISS, Shuttle, Constellation)	NASA Partnerships (COTS, LSP, Comm'l Crew)	Lead U.S. Corporation (AT&T/Bell)	International Authority (PA-NYNJ, TVA, CERN)	International Corporation INTELSAT/Fannie Mae/Freddie Mac
International Partners					
Private Investment					
Quick Debt Capital					
Economic Benefit					
Innovation					
Non-govt Customers					
Management Efficiency					
Econ Valuable Use Rights					
Political Sustainability					
Strategic Flexibility					

Summary of Benefits of International Lunar Authority modeled after CERN & PANY-NJ

- Trusted by Industry as a Good Partner (increasing investment)
- More Politically Sustainable over the Long-term
- More effective Long-term Planning
- Can Borrow Funds to Manage Short-term Challenges
- Politically Acceptable to Allocate Lunar Utilization Rights
- Resolves Political Battle among Moon & Mars advocates
- Improved Employee and Expertise Retention
- Improved Management Tools and Practices
- More Efficient Procurement
- Increased Innovation
- U.S. Efficiently shares costs with International Partners

Life Cycle Costs – ELA Scenario (Variant)

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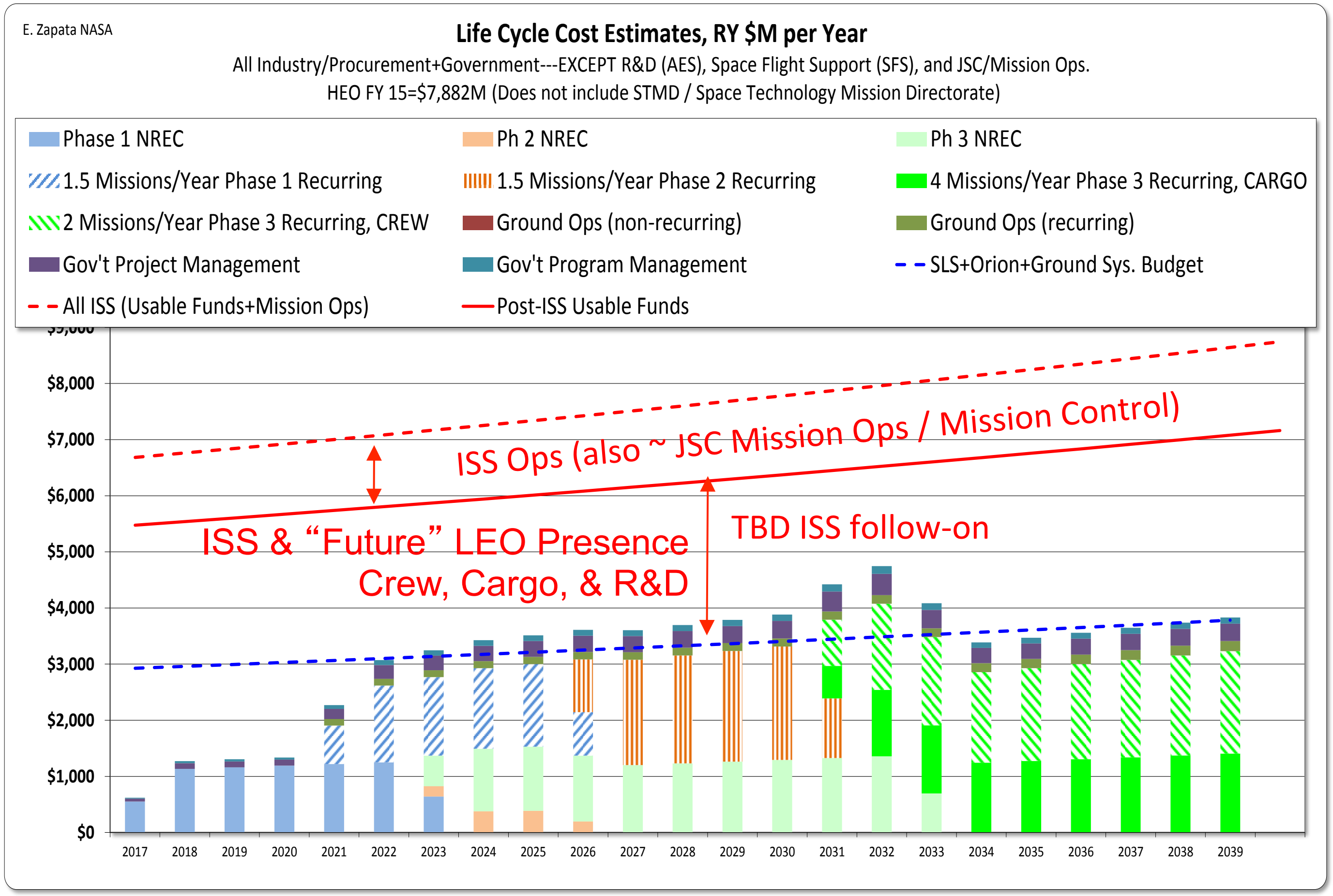
Variant: 1.5 Missions per year (Phase 1 and 2)



- Reduce operational missions in Phases 1 & 2 to fit within budget constraints
- We don't assume any efficiency in a continuing NASA LEO presence (pre and post-ISS), which could cover the ELA life cycle cost profile slightly overshooting a ~ $3B a year cap

Summary of Study Conclusions

Implications Near-term Human Return Moon

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- Technically feasible to return humans to the surface of the Moon within a period of 5-7 years from authority to proceed
  - Assumes COTS/CRS and Commercial Crew style partnerships
- Could be accomplished by end of 2nd term of next President
- Estimated cost is $10 Billion (+/- 30%) for <u>two independent commercial providers</u>, or about $5 Billion for each provider
    - Constellation cost of "first boots on the Moon" = $120 Billion
  - Did not estimate cost for a single provider with no competition
    - No hard empirical data available
- ELA Cost of Duplicating Apollo (6 sortie missions)
  - $12 Billion (+/- 30%), FY15$
    - Cost of Apollo was ~$140 Billion (FY15)

Summary of Study Conclusions

Implications Permanent Human Base on Moon

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- Phase 3: Permanent lunar base possible in 2031-35
  - Providing …
    - 2 human missions (6 month visits) per year
      - 4 humans permanently on surface of Moon
    - 4 cargo delivery missions/year to surface of Moon
    - 200+ MT propellant/year delivered to lunar orbital depot
  - All within a $2.8 Billion (FY15) budget
    - **Achievable within NASA's <u>existing</u> deep space human spaceflight budget**
  - Total estimated cost, from start to initial permanent ops
    - **$40 Billion, (+/- 30%), FY15$, spread over 12-18 years**
  - Assumes a new partnership — like an International Lunar Authority — is set up to mitigate long-term business risks

Summary of Study Conclusions

Implications for Private & Other Govt Space Travel

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- Assuming a private operational lunar base
  - With an anchor tenant customer covering fixed costs
- Many nations, and many private citizens, can afford to purchase a commercial trip to surface of the Moon
  - Phase 1/2: ~$600-700M (FY15) per round-trip ticket
    - Small lunar lander with Earth-based propellant
    - 1 passenger, 1 pilot
  - Phase 3: ~$150-200M (FY15) per round-trip ticket (polar base)
    - Large reusable lunar lander with Lunar-based propellant
    - 3 passengers, 1 pilot

Summary of Study Conclusions

Implications for NASA Missions to Mars

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- A commercial lunar base can reduce costs of Mars
  - Propellant is 80% of mass launched for Mars missions
    - 200MT/year of Propellant in L2 might cost NASA ~$3B/yr (FY15)
  - Which could be worth >$10 Billion per year to NASA
    - Based on costs avoided from launching all that mass from Earth
  - Reduces SLS launches required per human mission to Mars
    - From as many as 12 to as few as 3 SLS launches total per mission
    - Mars/SLS becomes more technically, economically & operationally viable
  - Enables a reusable Mars cycler that can be refueled at L2
    - Reusability for Mars systems could transform cost of trips to Mars
- A permanent commercially-operated lunar base can:
  - **Substantially pay for itself by exporting propellant to NASA for Mars**

Summary of Study Conclusions
Public Benefits

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- **Economic Growth**: Commercial partnership will significantly increase economic growth opportunities
- **National Security**: Will create long-term American dominance in key strategic sectors (launch, robotics, orbital operations)
- **Diplomatic/Leadership**: An American-led lunar base, led by free people and founded upon free enterprise, will be the "ultimate shining city on the hill" for the entire world to see.
  - Significant soft power messaging
- **Innovation/Technology**: Will drive advances in robotics, additive manufacturing, environmental tech, ISRU, etc.
- **STEM/Inspiration**: Many opportunities for involving next generation. Private businesses operating, and private citizens landing, on Moon is inspirational.
  - Affordably sending people to Mars is also.

Summary of Study Conclusions
Independent Review Team

- ***"On behalf of the Independent Review Team, I commend you and your Team for the impressive Study. Although a lot of work remains to bring the Architecture, Cost and Schedule to the next level of definition, the work of your Team provides an excellent foundation for the next Phase of the Evolvable Lunar Architecture development."***
  - Joseph Rothenberg

    NASA Associate Administrator for Human Spaceflight, 1998-2001

    Chairman of Independent Review Team

Questions?

NexGen Space LLC

Contact:

spacepolicy@me.com

Study Final Report:

https://www.researchgate.net/publication/280099331_Economic_Assessment_and_Systems_Analysis_of_an_Evolvable_Lunar_Architecture_that_Leverages_Commercial_Space_Capabilities_and_Public-Private-Partnerships